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Physical Building Information Modeling for Solar Building Design and Simulation – Annual Report 2010

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Project Activities and Findings

What have been your major research and education activities (experiments, observations, simulations, presentations, etc.)?

Our major research activities include:

1. Research on physical modeling methods

   We have conducted a more thorough literature research on physical modeling methods. We investigated solar building simulation tools including DOE-2.1e, EnergyPlus, F-Chart, PV F-Chart, TRNSYS, Ecotect, DAYSIM, Radiance, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Loads Toolkit. We examined the Loads Toolkit documentation, source code, examples, and related algorithms in various publications. Table 1 shows the software tools we have investigated and their applications in solar building simulations.

   Table 1. Software tools and their applications in solar building simulations

#	High-Performance Building Elements / Tools used for Simulations	Radiance	DAYSIM	PVF-CHART	F-CHART	TRNSYS	EnergyPlus	DOE-2.1e	STAR CCM	ESPR	HAP	TRACE	BLAST

1	**Solar Thermal**	-	-	-	C	C	P	P	-	-	-	-	P
2	**Solar Photovoltaic**	-	-	C	-	C	P	-	-	-	-	-	-
3	**Daylighting**	C	C	-	-	P	P	P	-	P	-	-	-
4	**Building Thermal (Envelope)**	-	-	-	-	C	C	C	-	C	-	-	C
5	**Building Thermal (Secondary Systems)**	-	-	-	-	C	C	C	-	C	-	-	C
6	**Building Thermal (Primary Systems)**	-	-	-	-	C	C	C	-	C	-	-	C
7	**Radiation Network**	-	-	-	-	P	C	P	-	-	-	-	P
8	**3D Air Flow Analysis**	-	-	-	-	P	P	-	C	P	-	-	-
9	**Geometry/ Shades**	C	C	-	-	C	C	P	-	C	-	-	P
10	**Loads**	-	-	-	-	C	C	C	-	C	C	C	C
11	**Systems**	-	-	-	-	C	C	C	-	C	-	-	C
Legend "C"- Complete analysis "P"- Partial analysis "-" - Feature not available													

2. Research on Building Information Modeling (BIM) simplification methods, BIM topology, and data modeling

   We have conducted more literature research on BIM simplification methods. We investigated the applications of BIM Application Programming Interface (API) and BIM-based parametric modeling that can be used for extracting BIM data for simplification. We studied the differences of data modeling and model topology between BIM (e.g. Industry Foundation Classes or IFC and Autodesk Revit) and thermal simulation models (e.g. ASHRAE Loads Toolkit and DOE-2.1e). We have experimented with BIM API to export database to analyze connectivity of BIM, such as room-door-room, room-wall, window-wall associations.

3. Linking BIM-OOPM (Object-Oriented Physical Modeling) and integrating P-BIM (Physical BIM)

   We have investigated an OOPM language (Modelica) and its modeling methods more extensively for linking BIM-OOPM. We have experimented on direct P-BIM integration through prototyping (detailed in 6. Prototyping below).

4. Experiments - solar thermal simulations

   We have created a high performance office building in BIM (Figure 1) and conducted experiments for integrated solar thermal simulations using a traditional tool (DOE-2.1e). The building features impacting solar simulations include: Trombe wall, south windows, clerestory, photovoltaic panels, etc. The simulations are conducted for two locations (Houston and Denver) of different climates. A series of experiments have been done for different combinations of the building features (Table 2 shows the combinations), and their results are compared with a base case energy model (Figure 2). Hand calculations have also been done for validating the software calculations.

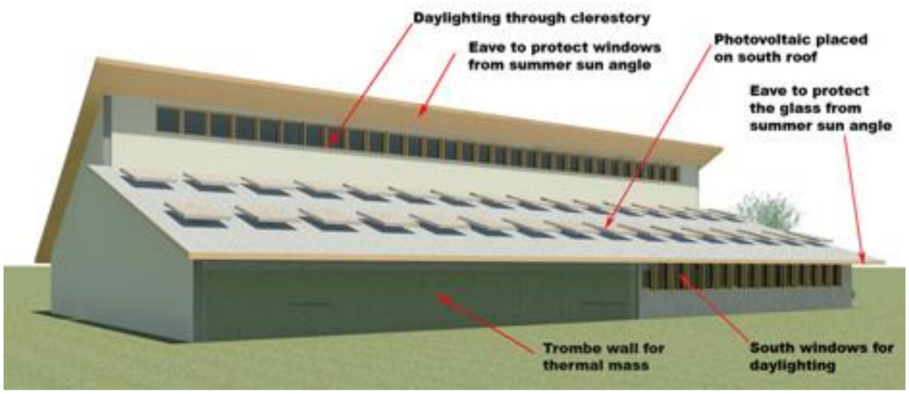

Figure 1. BIM model of the office building for solar simulations, Denver, 12 noon on August 25th 2010.

Table 2. Complex office building features matrix (in Houston) for solar simulations.

ID LETTER	ID NAME	FILE NAME	PBIM FOLDER (FOLDER LOCALIZATION)	HOUSTON, TX	DESIGN DAYS	BUILDING OVER THE SITE	BUILDING LIFT 10 ft.	FLOOR	OCCUPANCY SCHEDULE	LIGHTING SCHEDULE	EQUIPMENT SCHEDULE	INFILTRATION	SYSTEM-TYPE: SUM	SYSTEM-TYPE: VAVS	PLANT	PEOPLE	SOUTH WINDOW	NORTH WINDOWS	DOORS	CLERESTOREY	TROMBE WALL	SOLAR THERMAL	DAYLIGHTING SENSORS
A	BASECASE	01A1a_0a	VAVS	X	X		X							X									
B	CASE 1a	01A1a_1a	VAVS (FLOOR = WALL)	X	X		X	X						X									
C	CASE 1ba	01A1a_1ba	VAVS (HEAVY CONCRETE SLAB ONLY (25' X 50'))	X	X		X	X						X									
D	CASE 1ca	01A1a_1ca	VAVS (HEAVY CONCRETE SLAB ONLY (50' X 50'))	X	X		X	X						X									
E	CASE 1da	01A1a_1da	VAVS (HEAVY CONCRETE SLAB ONLY (50' X 100'))	X	X		X	X						X									
F	CASE 1ea	01A1a_1ea	VAVS (HEAVY CONCRETE SLAB ONLY (50' X 150'))	X	X		X	X						X									
G	CASE 1fa	01A1a_1fa	VAVS (HEAVY CONCRETE SLAB ONLY (50' X 200'))	X	X		X	X						X									
H	CASE 1ga	01A1a_1ga	VAVS (HEAVY CONCRETE SLAB (50' X 100') + 4" POLYSTYRENE)	X	X		X	X						X									
I	CASE 1ha	01A1a_1ha	VAVS (HEAVY CONCRETE SLAB (50' X 100') + 20" POLYSTYRENE)	X	X		X	X						X									
J	CASE 2	01A1a_2a	VAVS + Plant	X	X	X		X			X			X	X								
K	CASE 3	01A1a_3	SUM + Plant + Trombe wall	X	X	X		X			X		X		X						X		
Ka	CASE 3a	01A1a_3a	VAVS + Plant + Trombe wall	X	X	X		X			X			X	X						X		
L	CASE 4	01A1a_4a	VAVS + Plant + South window	X	X	X		X			X			X	X		X						
M	CASE 5	01A1a_5a	VAVS + Plant + North windows	X	X	X		X			X			X	X			X					
N	CASE 6	01A1a_6a	VAVS + Plant + Clerestory	X	X	X		X			X			X	X					X			
O	CASE 7	01A1a_7a	VAVS + Plant + South window + Clerestory	X	X	X		X			X			X	X		X			X			
P	CASE 8	01A1a_8a	VAVS + Plant + South window + north windows + Clerestory	X	X	X		X			X			X	X		X	X		X			
Q	CASE 9	01A1a_9a	VAVS + Plant + Trombe wall + South window + Clerestory	X	X	X		X			X			X	X		X	X		X	X		
R	CASE 10	01A1a_10a	VAVS + Plant + Trombe wall + South window + north windows + Clerestory	X	X	X		X			X			X	X		X	X			X		
S	CASE 11	01A1a_11a	VAVS + Plant + Trombe wall + People + Occupancy sched + South window + north windows + Clerestory	X	X	X		X	X		X			X	X	X	X	X		X	X		
T	CASE 12	01A1a_12a	VAVS + People + Occupancy sched + South window + north windows + Clerestory + DHW	X	X	X		X	X		X			X	X	X	X	X		X		X	
U	CASE 13	01A1a_13	SUM + South window + north windows + Clerestory + DHW	X	X	X		X			X		X		X		X	X		X		X	
Ua	CASE 13a	01A1a_13a	VAVS + South window + north windows + Clerestory + DHW	X	X	X		X			X			X	X		X	X		X		X	
V	CASE 14	01A1a_14a	VAVS + Plant + South window + north windows + Clerestory + Daylighting sensors	X	X	X		X			X			X	X		X	X		X			X

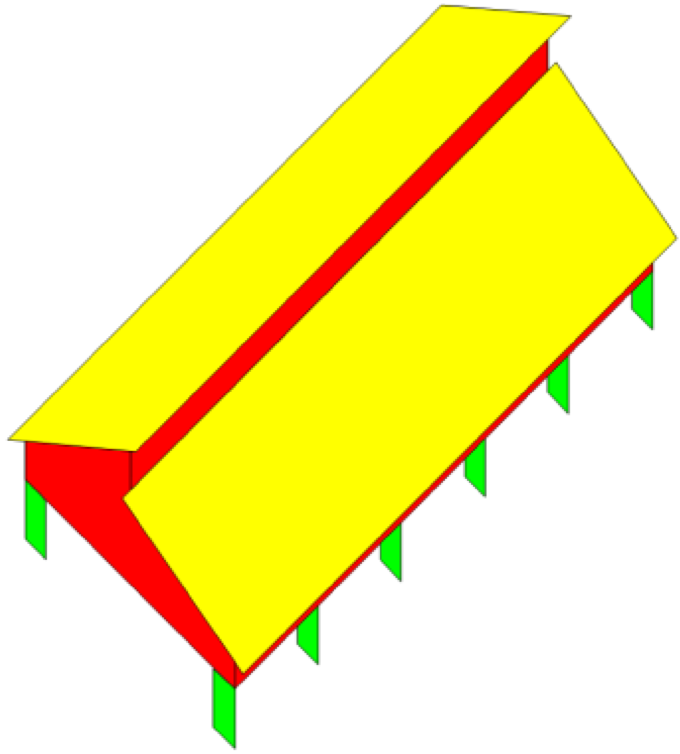

Figure 2. Base case energy model of the complex office building

5. Experiments – preliminary daylighting Analyses

   We have done preliminary daylighting analyses with traditional tools including DOE-2.1e, DAYSIM and Radiance, as part of the integrated solar building simulations. We used the same office building model with two sensors to compute the illuminance. Figure 3 shows the 3D visualization of DOE-2.1e input file of the building and the sensors. Figure 4 shows the 3D visualization of the Ecotect input file of the building.

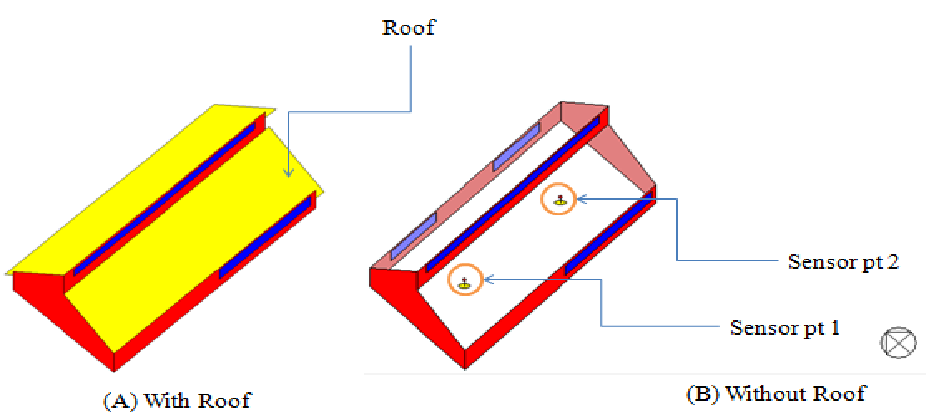

Figure 3. (A) DrawBDL visualization of the DOE-2 input file for the daylighting simulation with roof; (B) showing the sensors in the space without the roof.

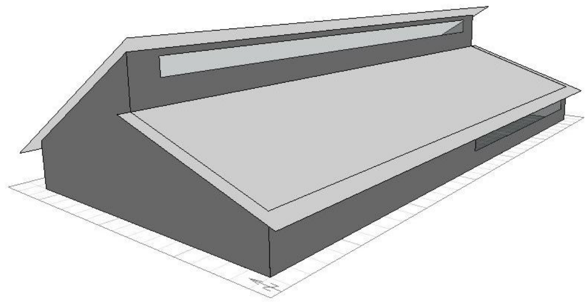

Figure 4. 3D visualization of the Ecotect model of the building for daylighting simulation.

The experiments helped us better understand the existing tools in solar building design and simulation, and will enable us to choose appropriate tools for building our P-BIM prototype. Also, they provided base cases against which we will evaluate our new methods.

6. P-BIM prototyping

We have created a preliminary P-BIM prototype for integrating BIM and a sample component of thermal simulation. Exploring the use of Autodesk Revit Architecture, its API, and ASHRAE Loads Toolkit, we created a sample building's BIM model and developed a method to link the Object-Oriented Programming (in C#) of Revit and the procedural calculation subroutines (in Fortran 90) of Loads Toolkit. The BIM model, with existing geometric and material information and user-defined physical parameters, can be used directly and automatically to compute building energy properties. This way, the need to manually convert BIM data to simulation input files is eliminated. For demonstration, we have completed a sample case study for calculating Infiltration Flow Rate directly in BIM, based on Radiant Time Series samples in ASHRAE Loads Toolkit (Figure 5). The sample of Infiltration Flow Rate was chosen for its simplicity without loss of generality (Figure 6 and 7). The BIM model and calculation results are shown in Figure 8. We are currently working on a more complex case of calculating thermal conduction in BIM.

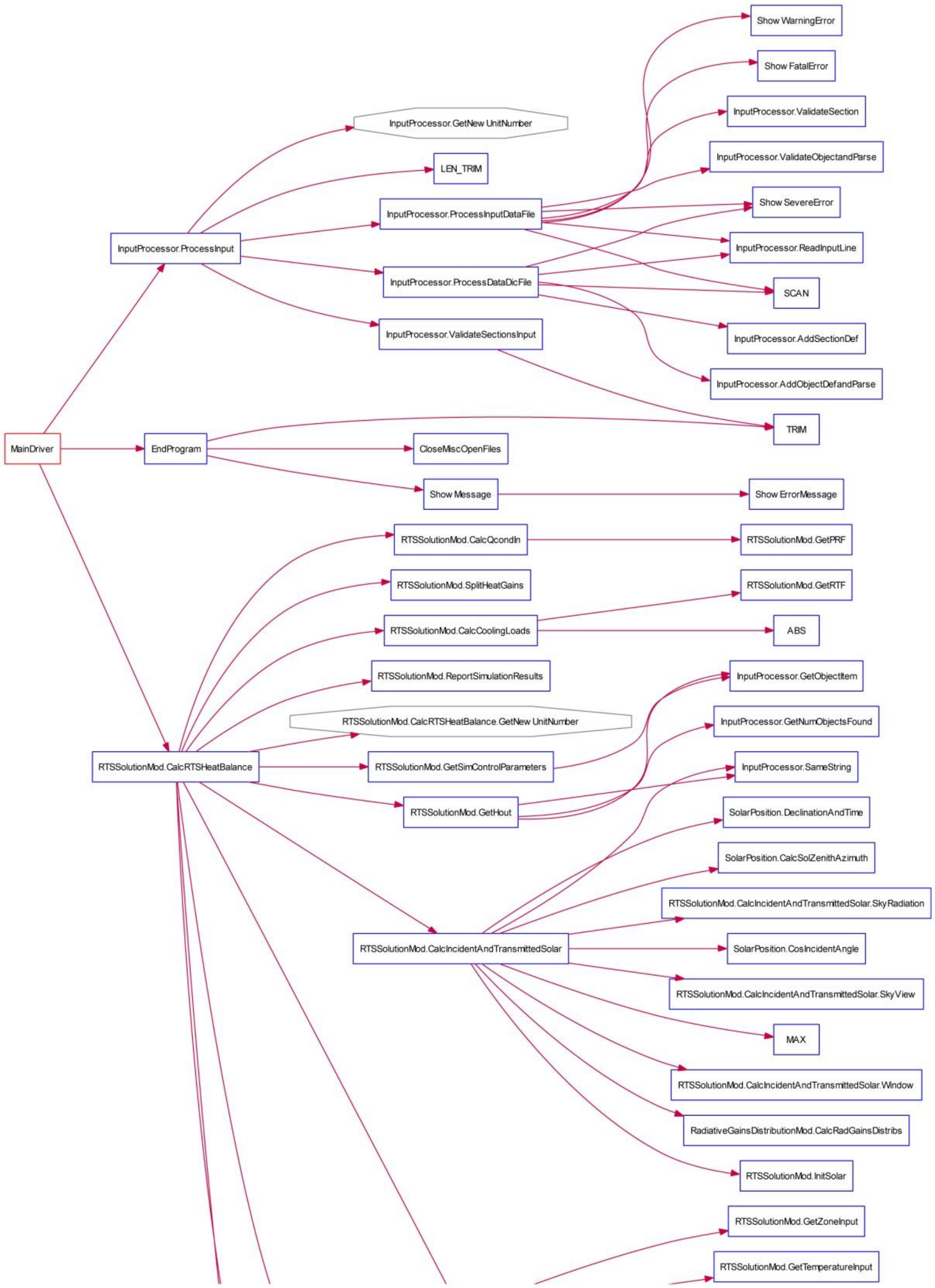

Figure 5. Algorithm flowchart of Radiant Time Series (ASHRAE Loads Toolkit), showing modules, subroutines, and functions in Fortran 90.

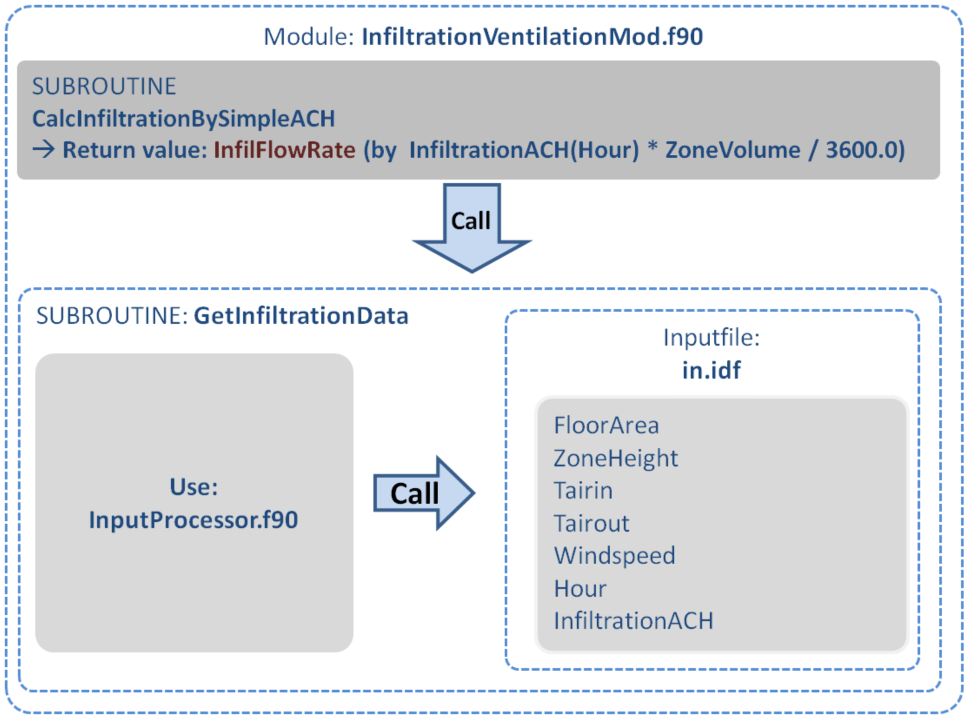

Figure 6. Data flow for the calculation of Infiltration Flow Rate in ASHRAE Loads Toolkit

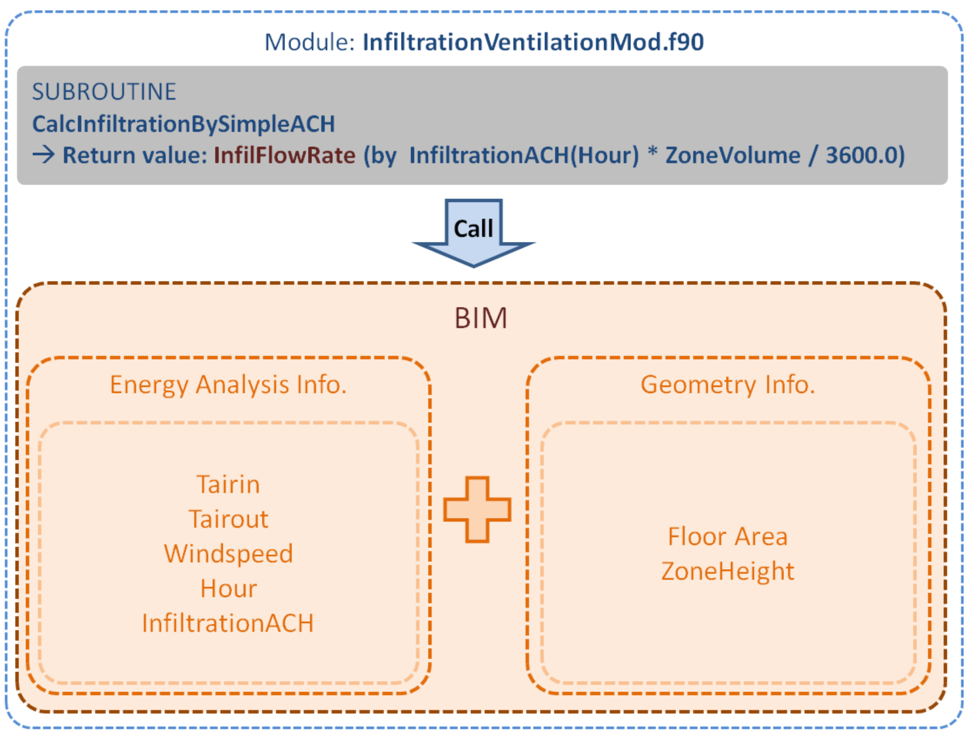

Figure 7. Data flow for the calculation of Infiltration Flow Rate in the P-BIM prototype

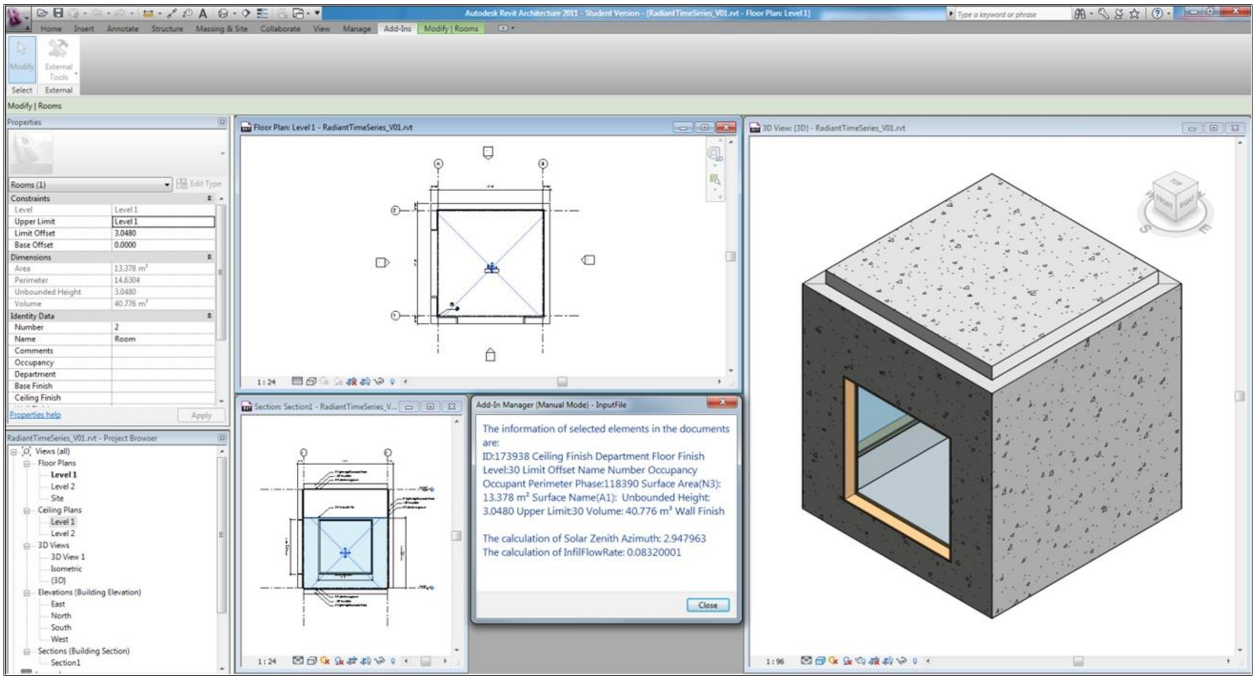

Figure 8. BIM model and the results of Infiltration Flow Rate calculation

Our major education activities include:

1. The project provided subjects and support for Ph.D. studies. Four Ph.D. dissertations in solar building design, daylighting simulation, BIM-based urban planning, and building data modeling, which are closely related to the project are in progress.

2. Graduate level Directed Study courses in related topics are offered to students working in this project. In addition, two of the students are currently taking or auditing the graduate BIM class taught by Dr. Wei Yan.

3. Dr. Jeff Haberl organized TRNSYS training at Texas A&M University, and our students in the project have participated in the training.

4. Dr. Wei Yan presented the project proposal and the progress to ASHRAE Student Branch at Texas A&M University, October 7, 2010. The audience includes undergraduate and graduate students in Architecture and Mechanical Engineering. (http://ashrae.tamu.edu/pictures.htm).

Figures are attached in the PDF file.

What are your major findings from the activities identified above?

Our major findings include:

1. Through the simulation and preliminary analyses of the office building model, we demonstrated that an integrated solar building model simulation can be achieved. Hand calculation validated the software calculation in the experiments. Reasonable simulation results have been achieved for different combinations of building features. The simulations will provide benchmark results for later integrated P-BIM simulation of solar buildings.

2. Comparison of results between two daylighting simulation software tools (DOE-2.1e and DAYSIM) leads to the conclusion that DAYSIM and its simulation engine Radiance will be potentially useful for integrated P-BIM, while a direct access to the simulation subroutines from BIM is needed for the integration. The present study provides a brief idea of how the daylighting analyses are done using different tools, what the input file structures they have, and how these can be incorporated into P-BIM. The subsequent research in this area will focus on the process of linking BIM and the daylighting simulation tools.

3. Different data structures and modeling concepts between BIM (based on Object-Oriented Programming or OOP) and energy simulation software (based on Procedural Programming) lead to different data access mechanisms that will impact building energy simulation. For example, in BIM, geometric data that are calculated properties of a building element are read-only, but they may be writable in energy simulation, which may lead to input errors. In ASHRAE Loads Toolkit, during calculation, accessing building data from input files is made multiple times from different subroutines, which is inefficient from the point of view of accessing building models. In addition, some input data are embedded in the calculation subroutines while a more reasonable way is to store the data in external sources. The differences of the data modeling and data access mechanisms become challenges of P-BIM and the understanding of the differences will help integrate BIM and energy simulation. Our prototype demonstrates that procedural programming-based thermal simulation processes can be integrated into OOP-based BIM through computer programming methods. The complex, inefficient, sometimes random and error prone process of accessing building input files in thermal simulations can be substituted by more organized, structured, efficient, and reliable access of BIM data.

4. The preliminary P-BIM prototype demonstrates that the P-BIM methods and algorithms can extract building data from a BIM model directly and use the data in building energy simulation. In addition, different granularity levels of building energy calculation can be achieved in a BIM model, since subroutines in the simulation (ASHRAE Load Toolkit as a sample) can be directly called within the BIM model.

Contributions

Contributions within Discipline

How have your findings, techniques you developed or extended, or other products from your project contributed to the principal disciplinary field(s) of the project? Please enter or update as appropriate.

Our findings demonstrated that new methods have the potential to facilitate the integration of BIM and building energy simulation that is expected to assist informed decision-making of solar building design. The findings also demonstrated the potentials of the methods for reducing the interoperability problem that exists between building design models and energy simulation models.

Contributions to Other Disciplines

How have your findings, techniques you developed or extended, or other products from your project contributed to disciplines other than your own (or disciplines of colleagues and associates not covered under "Contributions within Discipline")? Please enter or update as appropriate.

The project is cross-disciplinary in the fields of architecture, building science, and computer technology. The contributions of the project help integrate architecture and building science with computer technology. In addition, our methods demonstrated that specific domain modeling (in our case, BIM) can be integrated into more general physical simulation (in our case, thermal).

Contributions to Human Resource Development

How have results from your project contributed to human resource development in science, engineering, and technology? Please enter or update as appropriate.

Our project helped prepare students in architecture and building science for academic and professional careers in sustainable building design and research.

Contributions to Resources for Research and Education

How have results from your project contributed to physical, institutional, and information resources for research and education (beyond producing specific products reported elsewhere)? Please enter or update as appropriate.

1. With the support from the NSF grant and our department and college, we have built a new BIM-SIM (Building Information Modeling and Simulation) research and education lab, where both undergraduate and graduate students work on research projects, among which P-BIM is one of major projects. We installed software and hardware funded by this NSF grant in the lab. We have also set up web-based project collaboration and management systems. The facility and the equipment can be used further for research and education in the fields of sustainable building design.
2. Our project produced a preliminary software prototype of P-BIM (which can be further developed into a complete prototype) and solar building test models, which can contribute to the information resources for research and education in solar building design and simulation, as well as general building energy simulation.

Contributions Beyond Science and Engineering

How have results from your project contributed to the public welfare beyond science and engineering (e.g., by inspiring commercialized technology or informing regulatory policy)? Please enter or update as appropriate.

The resulting preliminary prototype, models, and methods, when further developed into a more comprehensive prototype, energy models, and guidelines, can be used for creating commercialized software tools for solar building design and simulation.

Acknowledgement

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